

# Electroweak Penguin $B$ Decays at Belle

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**Abstract.** We summarise the most recent results of the Belle experiment about flavour changing neutral current (FCNC) radiative and (semi-) leptonic  $B$  decays. In particular, we report about the first observation of the decays  $B \rightarrow K^* \ell^+ \ell^-$ ,  $B \rightarrow \phi K \gamma$ , the inclusive  $B \rightarrow X_s \ell^+ \ell^-$ . We also report about searches for  $B \rightarrow \ell^+ \ell^-$  decay and for  $CP$  asymmetries in  $B \rightarrow K^* \gamma$ .

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## 1 Introduction

Since the first observation of a penguin decay ten years ago [1], radiative  $B$  decays have been a powerful tool to constrain physics beyond the Standard Model. Today we enter an era of precision measurements as the error on the  $B \rightarrow K^* \gamma$  branching fraction is about to become systematics-dominated and as we start to observe more rare decays like  $b \rightarrow s \bar{s} s \gamma$ . In the future  $b \rightarrow s \gamma$  transitions may be used to probe the kinematic properties the  $B$  decays, which is useful to understand the  $V_{ub}$  extraction from semileptonic decays, and may also provide a handle on  $V_{td}$  once the Cabbibo-suppressed  $b \rightarrow d \gamma$  decays are seen.

At the price of an additional suppression by  $\alpha_{e.m.}$ , one gets flavour-changing neutral current (FCNC) semileptonic  $b \rightarrow s \ell \ell$  decays, where the lepton pair provides other observables, like the forward-backward charge asymmetry, which are much more powerful to constrain the Standard Model and its extensions.

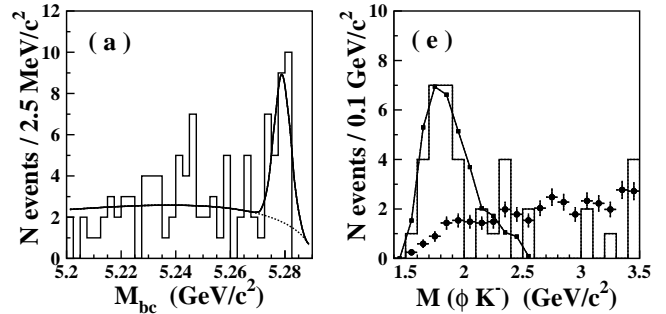
In this report we summarise the latest results from Belle [2] about the above mentioned decays and also about purely leptonic  $B \rightarrow \ell \ell$  decays.

## 2 Radiative decays

While we start to perform precise branching fraction and  $CP$  asymmetry measurements in the  $B \rightarrow K^* \gamma$  decay, which cannot be considered as “rare” at  $B$  factories anymore, most of the partial width of  $B \rightarrow X_s \gamma$  is yet still unknown. Thus the search for more exclusive final states is needed to achieve a better understanding of the hadronic structure of this decay.

### 2.1 First observation $B \rightarrow K \phi \gamma$

Using  $90 \text{ fb}^{-1}$ , we observe the decay  $B^- \rightarrow \phi K^- \gamma$  [3]. This is the first observation of a radiative  $b \rightarrow s \bar{s} s \gamma$  pro-



**Fig. 1.**  $m_{bc}$  fit (left) and  $m_{\phi K}$  (right) for  $K \phi \gamma$  final state. The measured (solid)  $m_{\phi K}$  distribution is compared to MC simulations basing on a phase-space model (circles) or adjusted to follow the data (squares connected by a line).

cess. The decay is reconstructed using a high-energy photon, two oppositely charged kaons required to form the  $\phi$  mass within  $10 \text{ MeV}$  ( $\sim 3\sigma$ ), and one additional  $K^-$  or  $K_S^0$ . We observe  $21.6 \pm 5.6$  events in the charged mode, (corresponding to a statistical significance of  $5.5\sigma$ ), and  $5.8 \pm 3.0$  events in the neutral mode ( $3.3\sigma$ ). The preliminary measured branching fractions are:

$$\begin{aligned} \mathcal{B}(B^- \rightarrow K^- \phi \gamma) &= (3.4 \pm 0.9 \pm 0.4) \cdot 10^{-6} \\ \mathcal{B}(B^0 \rightarrow K^0 \phi \gamma) &= (4.6 \pm 2.4 \pm 0.6) \cdot 10^{-6}. \end{aligned}$$

In the latter mode we also give an upper limit for the branching fraction at  $8.3 \cdot 10^{-6}$  at 90% confidence level.

The beam-constrained mass fit for the charged mode is shown in Fig. 1 (left). The right hand side figure shows that the  $\phi K^-$  mass distribution differs from a naive three-body phase-space decay model. Yet the low statistics do not allow to draw any conclusion about the structure.

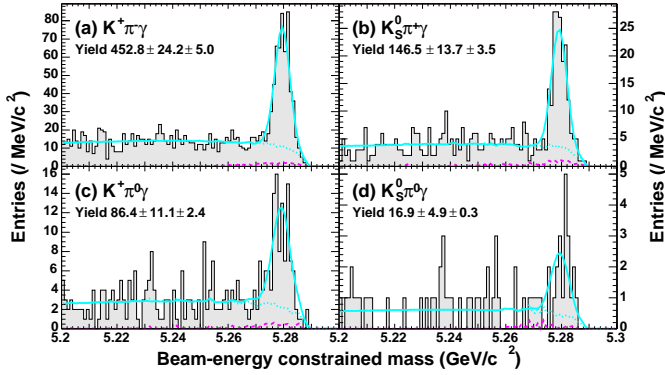


Fig. 2. Beam-constrained mass fits for  $K^*\gamma$  final states.

## 2.2 $CP$ asymmetry in $B \rightarrow K^*\gamma$

Among radiative penguin decays, the  $B \rightarrow K^*\gamma$  decay allows the most precise measurements. We observe 700 such decays [4], using a  $78 \text{ fb}^{-1}$  data sample and reconstructing the  $K^*$  in all visible final states  $K^+\pi^-$ ,  $K_S^0\pi^0$ ,  $K^+\pi^0$ ,  $K_S^0\pi^+$  (charge conjugation is implied throughout this report except where mentioned). The corresponding beam-constrained mass ( $m_{bc}$ ) distributions are shown in Fig. 2. The preliminary branching fractions are found to be

$$\mathcal{B}(B^0 \rightarrow K^{*0}\gamma) = (4.09 \pm 0.21 \pm 0.19) \cdot 10^{-5}$$

$$\mathcal{B}(B^+ \rightarrow K^{*+}\gamma) = (4.40 \pm 0.33 \pm 0.24) \cdot 10^{-5},$$

where the first error is statistical and the second systematic. Fitting the event yields separately for the two flavour eigenstates of the  $B$  meson (thus excluding the  $K_S^0\pi^0\gamma$  final state) we get a measurement of the  $CP$  asymmetry:

$$A_{CP}(B \rightarrow K^*\gamma) = -0.001 \pm 0.044 \pm 0.008.$$

## 3 Semileptonic Penguin decays

Semileptonic FCNC decays  $B \rightarrow X_s \ell^+ \ell^-$  are known since the first observation of the  $B \rightarrow K \ell^+ \ell^-$  decay by Belle [5]. Here we report about the first observation of the long awaited  $B \rightarrow K^* \ell^+ \ell^-$  decay and about a semi-inclusive analysis.

### 3.1 First observation of $B \rightarrow K^* \ell \ell$

This analysis [6] searches for  $B \rightarrow K^* \ell \ell$  and  $B \rightarrow K \ell \ell$  using the full  $140 \text{ fb}^{-1}$  data sample available in Summer 2003. The candidates are formed using an oppositely-charged lepton pair (muons or electrons) and a  $K^+$ ,  $K_S^0$ , or a  $K^*$  candidate formed as  $K^+\pi^-$ ,  $K_S^0\pi^+$  or  $K^+\pi^0$ . The lepton pair is vetoed if its mass is below  $140 \text{ MeV}/c^2$ , or compatible with the  $J/\psi$  or  $\psi'$  masses. In the  $eeK^*$  case, we also consider  $ee\gamma$  and  $ee\gamma\gamma$  combinations to suppress the  $\psi^{(\prime)}$  background due to Bremsstrahlung. The fitted  $m_{bc}$  distributions are shown in Fig. 3. We observe  $36 \pm 8$

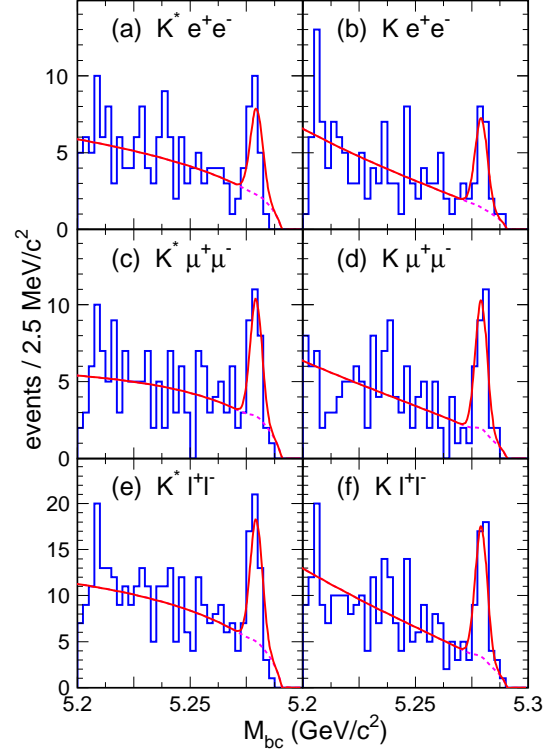


Fig. 3.  $m_{bc}$  fits for  $K^* \ell \ell$  and  $K \ell \ell$  final states.

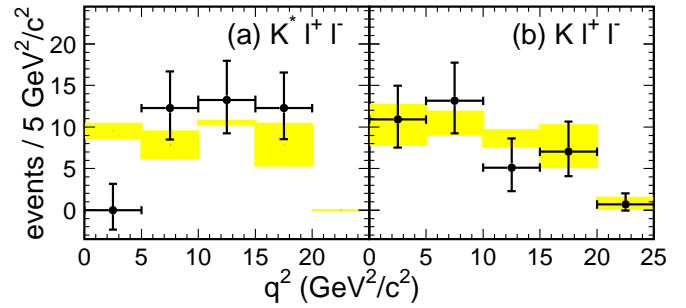


Fig. 4.  $q^2$  distributions for  $K \ell \ell$  and  $K^* \ell \ell$ . Points show data while bands show the expectation range of various models [7].

$B \rightarrow K^* \ell^+ \ell^-$  and  $38 \pm 8$   $B \rightarrow K \ell^+ \ell^-$  events, with statistical significances of  $5.7\sigma$  and  $7.4\sigma$  respectively. We extract the following preliminary branching fractions:

$$\mathcal{B}(B \rightarrow K^* \ell^+ \ell^-) = (11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2) \cdot 10^{-7}$$

$$\mathcal{B}(B \rightarrow K \ell^+ \ell^-) = (4.8^{+1.0}_{-0.9} \pm 0.3 \pm 0.1) \cdot 10^{-7}$$

where the third error is due to model-dependence. Fig. 4 shows the measured squared dilepton mass ( $q^2$ ) distributions compared to theoretical predictions [7].

### 3.2 Semi-inclusive analysis

We performed a semi-inclusive analysis using  $60 \text{ fb}^{-1}$  [8]. In this case the lepton pair is combined with any of 18

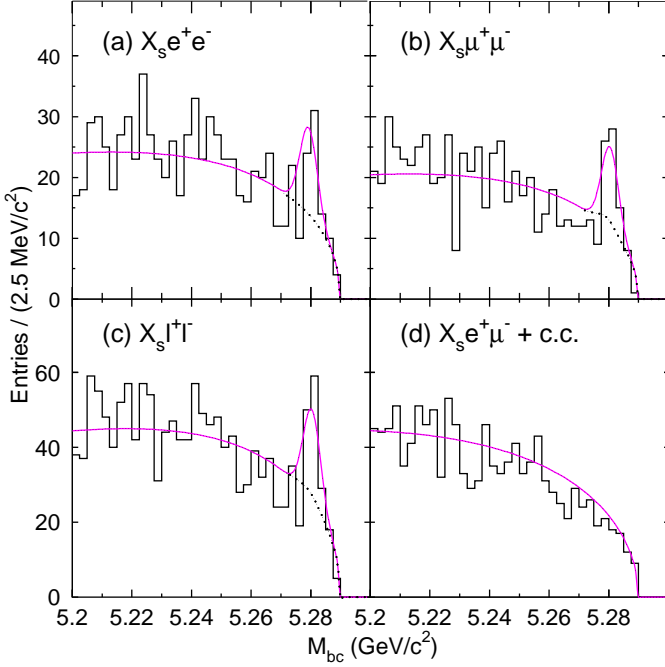


Fig. 5.  $m_{bc}$  fits for  $X_s ll$  final states.

combinations made of one kaon ( $K^\pm$  or  $K_S^0$ ) and up to four pions, one of which may be neutral. The so formed  $X_s$  system is required to have a mass below  $2.6 \text{ GeV}/c^2$ . The  $m_{bc}$  mass fits are shown in Fig. 5 for  $B \rightarrow X_s ee$ ,  $B \rightarrow X_s \mu\mu$  and the sum  $B \rightarrow X_s \ell\ell$ , where peaks are seen at the  $B$  mass. The forbidden  $B \rightarrow X_s e\mu$  mode is also shown as a control sample. We observe  $60 \pm 14^{+9}_{-5}$   $B \rightarrow X_s \ell\ell$  events with a statistical significance of  $5.4\sigma$ . The branching fractions are:

$$\mathcal{B}(B \rightarrow X_s \ell^+ \ell^-) = (6.1 \pm 1.4^{+1.4}_{-1.1}) \cdot 10^{-6} \quad (5.4\sigma)$$

$$\mathcal{B}(B \rightarrow X_s e^+ e^-) = (5.0 \pm 2.3^{+1.3}_{-1.1}) \cdot 10^{-6} \quad (3.4\sigma)$$

$$\mathcal{B}(B \rightarrow X_s \mu^+ \mu^-) = (7.9 \pm 2.1^{+2.1}_{-1.5}) \cdot 10^{-6} \quad (4.7\sigma).$$

## 4 Leptonic FCNC $B$ decays

Finally, we report about the search for the FCNC decays  $B \rightarrow ee$ ,  $B \rightarrow \mu\mu$  and  $B \rightarrow e\mu$ , using a data sample of  $78 \text{ fb}^{-1}$  [9]. The Standard Model (SM) branching fractions predictions for the first two decays are about  $10^{-10}$  and  $10^{-15}$  respectively, but they could be enhanced by two order of magnitude in models including two Higgs doublets or  $Z$ -mediated FCNC. Apart from the negligibly small contribution from neutrino oscillations, the  $B \rightarrow e\mu$  is forbidden in the SM, but could occur in some SUSY models or the Pati-Salam leptoquark model [10].

The selection is based on stringent requirements for the particle-identification of the two leptons and strong requirements for the  $q\bar{q}$  ( $q = u, d, s, c$ ) and  $\tau\tau$  background rejections. In particular, to favour  $B\bar{B}$  events, we require the presence of five charged tracks in the event.

We find no events in the signal box defined in the  $\Delta E$ – $m_{bc}$  plane, as shown in Fig. 6, while we expect about 0.2

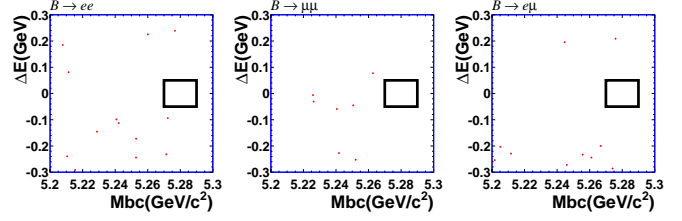


Fig. 6.  $\Delta E$  versus  $m_{bc}$  for  $ee$ ,  $\mu\mu$  and  $e\mu$  final states. The rectangles indicate the signal box.

to 0.3 events from background, depending on the mode. We set upper limits on the branching fractions as:

$$\mathcal{B}(e^+ e^-) < 1.9 \cdot 10^{-7} \quad (90\% \text{ CL})$$

$$\mathcal{B}(\mu^+ \mu^-) < 1.6 \cdot 10^{-7} \quad (90\% \text{ CL})$$

$$\mathcal{B}(e^\pm \mu^\pm) < 1.7 \cdot 10^{-7} \quad (90\% \text{ CL}).$$

The latter allows to set a 90% CL lower limit on the mass of the Pati-Salam leptoquark [10,11] at  $46 \text{ TeV}/c^2$ . The details of the extraction are given in Ref. [9].

## 5 Conclusion

While radiative  $B$  decays become tools to understand the QCD structure of the  $B$  meson, semileptonic FCNC decays become hot candidates to test extensions of the Standard Model. After a long wait, we finally observed the decay  $B \rightarrow K^* \ell\ell$ , opening the road to measurements of the lepton forward-backward asymmetry.

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